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FURROW DIKING OF SPRINKLER IRRIGATED CORN . . .

by Terry Howell

Corn (*Zea mays* L.) is a major crop grown on the U.S. Southern High Plains. In this region, corn typically has some of the greatest mean county yields because almost all the corn is produced under full irrigation regimes. Corn has a large seasonal irrigation requirement and a large evapotranspiration (ET) demand in the Southern High Plains region (Texas and New Mexico High Plains, Oklahoma Panhandle, southwestern Kansas, and southeastern Colorado). The Texas High Plains, like the whole region, has dramatically shifted from predominately graded furrow irrigation (90% in 1958) to slightly more than 50% sprinkler (mainly center pivot sprinklers) by 1994. The change in irrigation technology has reduced water applications and contributed to sustaining irrigated production in this region. The Texas High Plains irrigated area in 1994 exceeded 1.5 million ha and represented nearly 50% of all the cropped area in the region. Center pivot sprinklers, still growing in popularity, are well suited for irrigation in this region where water is a far more limited resource for irrigated agriculture than land. Musick et al. (1990) subdivided the Texas High Plains into three major climatic and crop zones – North Plains, Central Plains, and the Southern Plains. The southern portion of the Texas High Plains is dominated by cotton (*Gossypium hirsutum* L.), while the northern portion is mainly a wheat (*Triticum aestivum* L.) and corn region. The central portion is a mixture of these main crops. Sorghum (*Sorghum bicolor* (L.) Moench) is produced in all subdivisions, but corn is the only grain crop consistently irrigated at its "full" irrigation requirement. Wheat, cotton, and sorghum are often deficit irrigated.

Irrigated corn area dramatically escalated from the late 1960s until the late 1970s in this region. It declined dramatically, too, during the next decade because of many economic factors (high energy prices, poor commodity prices, high interest rates, etc.). But, irrigated corn area in the Texas High Plains has approached 400,000 ha since the mid 1990s. Corn production area in the central portion of the Texas High Plains has stabilized at around 200,000 ha, but the northern portion (north of Amarillo) has dramatically expanded its corn production area and shows signs of continued expansion. This area has substantial groundwater resources; however, great concerns remain about resource economics and irrigated agriculture's sustainability in this region (Vaux et al., 1996; Gardner et al., 1996).

Six-row furrow diker

Corn has been grown on a wide-scale commercial basis for about 30 years in the Texas High Plains (a relatively short history compared with the other major irrigated crops in the region). Recent yields have often exceeded 12 Mg ha^{-1} in the Southern High Plains. However, more significant is the considerably higher ET for fully irrigated corn in the Texas High Plains compared with other sites in the Great Plains, United States, and world. Also, corn yields have shown a rather consistent increase during the past 20 years in this region. The

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mean regional irrigated sorghum yield has remained largely unchanged during this period, while both irrigated wheat and cotton yields have increased, but not as consistently as the corn yields. Generally, sorghum and wheat are considered more drought tolerant than corn and are produced under a wider diversity of irrigation capacities (flow rate per unit land area) that are not considered adequate for corn.

Surface Tillage for Sprinkler Irrigation

Various tillage techniques have been proposed to provide temporary storage of sprinkler applied water to reduce surface redistribution and runoff. The surface tillage types are usually implanted reservoir (dammer diking) or basin tillage (furrow diking) that places small dams at regular or systematic distances along a furrow (Jones and Stewart, 1990). The implanted reservoirs can be used in flat or bedded culture, while basin tillage requires a furrowed or bedded culture. Lyle and Dixon (1977) described a diking tool designed to capture rainfall and irrigations for beds and furrows. Furrow diking, traditionally, is used in a "clean" tilled system or occasionally in conservation ridge-till systems; however, implanted reservoirs can be used in higher residue conservation till systems. The commercial dammer-diker implement is used together with deeper chiseling. Oliveira et al. (1987) reported that the chiseling improved the hydraulic conductivity and that it was of greater importance in reducing runoff than the reservoir storage detention, which varied with implement depth from 16 to 21 mm and declined to 9 to 16 mm during the season. Aarstad and Miller (1973) used handmade basins spaced 0.6 m apart in furrows and found that they effectively eliminated runoff with applications of 5 to 9 mm on slopes from 3 to 7%. Basins were better than incorporating 11 Mg ha^{-1} of alfalfa (*Medicago sativa* L.) hay. Mickelsen and Schweizer (1987) studied continuous corn under high (384 kPa) and low (140 kPa) pressure center pivot system applicators in eastern Colorado that demonstrated 30% greater runoff with the low pressure system with conventional tillage on a 3.8% slope, but two ridge till systems reduced irrigation runoff to between 1 to 4%. Hackwell et al. (1991) studied runoff and infiltration with LEPA (low energy, precision application) with reservoir tillage, and they found increased infiltration and reduced runoff. They reported reservoir storage volumes near the end of the season that varied from 3 L for higher compaction to almost 4 L for lower compaction, and these had declined due to siltation from intense spring rains.

Basin tillage is an integral component of low energy, precision application (LEPA) irrigation (Lyle and Bordovsky, 1981). Howell et al. (1995) reported a rainfall storage volume of 50 mm for furrow dikes constructed on 0.75 m rows with a commercial diker. This would decline by one-half to 25 mm if alternate furrow LEPA irrigation was used. The smaller storage capacity of 8 to 12 mm with dammer-diker pits for alternate row LEPA would not provide enough storage capacity to avoid surface redistribution and/or runoff unless one or two day irrigation frequencies were used, which are nearly impractical with most center pivot sprinklers. Schneider and Howell (1999) measured runoff of 0 and 12% from 20-m long plots with spray irrigation with and without furrow dikes, respectively; while with LEPA they reported 22 and 52% runoff with and without dikes, respectively. For water applied in the "bubble" mode to alternate rows with ridge-till corn, Buchleiter (1992) measured runoff under LEPA of 30% of the applied water on slopes of 3 and 55% runoff from an 8% slope. Lyle and Bordovsky (1983) reported 2-year mean application efficiencies of 99% for LEPA, 84% for sprinkler, and 87% for furrows using basin tillage; and 88% for LEPA, 81% for sprinkler and 86% for furrow using conventional tillage. Hanson et al. (1998) studied the effects of furrow diking intervals and soil infiltration and reported that the actual infiltration uniformity was much less than the static hydraulic nozzle discharge uniformity of 95%. Fangmeier et al. (1990) recommended a furrow dike spacing of 2 m to obtain a uniformity coefficient of 0.8 and developed a "double-ended" drag sock to reduce dike erosion. Solomon et al. (1994) used the LEPA concept with basin tillage implemented on straight rows with a center pivot rather than circular rows and reported a storage capacity of nearly 66 mm.

Reservoir tillage uses a combination chisel with a paddle wheel to implant small reservoirs. Kincaid et al. (1990) reported reservoir tillage prevented runoff that was up to 43% of the applied water on conventionally tilled plots even for slopes up to 12%. Coelho et al. (1996) reported storage volumes for only about one day's ET of corn. Kranz and Eisenhauer (1990) and Spurgeon et al. (1995) compared reservoir tillage with conventional tillage and chiseling. Using a 50-mm application depth for application rates from 113 mm h^{-1} to 149 mm h^{-1}, Kranz and Eisenhauer (1990) measured runoff

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percentages of 25, 12, 8, and 41% for conventional tillage, basin tillage, reservoir tillage, and chiseling, respectively, on a 10% slope, and only 5, 5, and 8% runoff for conventional tillage, reservoir tillage, and chiseling, respectively on a 1% slope. Spurgeon et al. (1995) reported that reservoir tillage was more effective than basin tillage in maintaining soil water and enhancing crop yields on a 3.9% slope . They reported better results with low elevation spray application (LESA or in-canopy spray) compared to LEPA in the bubble mode.

Surface Tillage for Rainfall Capture

Basin tillage was initially developed for rainfall capture in semi-arid environments (Lyle and Dixon, 1977; Jones and Stewart, 1990) for dryland crop production. Generally, positive yield responses have been found in years with storm intensity and/or amounts that would be expected to produce significant runoff. McFarland et al. (1991) reported a yield decrease with corn in a year with above-average rainfall but did not find corresponding reduced leaf or soil nitrogen decreases from N leaching. In a drier to more normal rainfall year, they found no effect of diking on corn yield in the subhumid climate. Unger (1992) reported no increase in soil water or crop yield for sorghum or wheat with blocked furrows compared with no-till alone in a semi-arid environment at Bushland. Mickelson and Schweizer (1987) reported growing season runoff that varied from 12 to 32% of rainfall with the least amount using a strip-rotary till system. Wiyo et al. (2000) indicated “tied-ridging” (another name for furrow diking) would be more effective on fine textured soils than on coarse textured soils and may lead to waterlogging with seasonal rainfalls more than 900 mm with fine textured soils.

Objective

Resource constraints and production relationships to irrigation are vital information required by resource economists, agronomists, and engineers to provide advice for water resource planning. This paper summarizes the effects of surface tillage and irrigation levels on corn production in the semi-arid environment of the U.S. Southern High Plains.

MATERIALS AND METHODS

This study was conducted at the USDA-ARS Conservation and Production Research Laboratory at Bushland, TX (lat. 35E11' N; long. 102E06' W; 1170 m elevation MSL) during the 1997, 1998, and 1999 growing seasons. The Pullman clay loam soil at this site is classified as fine, mixed, superactive, thermic Torrertic Paleustoll, and the field slopes were approximately 0.3% or less. The soil is described by Unger and Pringle (1981) as slowly permeable because of a dense B21t horizon about 0.15 to 0.4 m below the surface. The plant available water holding capacity within the top 2.0 m of the profile is approximately 250 mm, but corn cannot fully exploit and extract the soil water below about 1.5 m (Tolk et al., 1998). A calcareous layer at about 1.5 m depth limits significant rooting and water extraction below this depth. This soil is common to more than 1.2 million ha of land in this region and about one-third of the sprinkler irrigated area in the Texas High Plains.

The irrigation system was a Valmont (Valmont Industries, Inc.,Valley, NE) three-span lateral move sprinkler system with a pressurized water supply via a 100 mm ID hard hose from hydrants. Senninger (Senninger Irrigation, Inc., Orlando, FL) LDN spray heads with double spray plates with 42 kPa pressure regulators (Senninger model PMR-MF) and 8.3 mm (#21) nozzles rated to flow at 0.465 L s^{-1} were spaced 1.5 m apart and about 1.8 m above the ground on PVC hose drops with 0.9 kg polyethylene (PE) weights to reduce wind swaying of the drops. The nozzle flow rates were selected to simulate the outer span of a 400-m long center pivot sprinkler with an irrigation capacity of approximately 8 mm d^{-1} (0.93 L ha^{-1} s^{-1}).

The cultural operations, agronomic, and irrigation details are given in Howell et al. (2000). The plots were each 13.7 m wide (E-W) (18 rows spaced 0.75 m apart) and approximately 40 m long (N-S). Plots were arranged so a drainage way with a berm permitted the plots to drain to the S and E while blocking any runon from the N side of the plots. Each plot was border diked on the E and W sides, and a 4.6-m wide guard plot separated water treatments in the E-W direction to permit manual system speed changes to adjust the application amount. All cultural operations were performed with standard 6-row farm equipment. Planting densities achieved mean field plant densities of 8 plants m^{-2} each year at harvest.

The experimental design was a complete randomized block design with three replications. The main treatments were surface geometries installed using various tillage regimes after planting including one that left the soil surface nearly flat (FT), one that formed a more traditional bed (BT), and one like the BT treatment but with furrow dikes (FD) installed with a trip-roll diker (Bigham Brothers, Inc., Lubbock, TX). Dike spacings varied but averaged about 1.8 to 2.0 m. The tillage plots and rows were perpendicular to the irrigation system travel path, and each plot was an entire span length with the next tower wheels running north of plot berm to prevent N-S water runon onto a plot. The experiment was rotated each season to a previous summer-fallowed field area.

The irrigation treatments were based on soil water depletion replenishment. The fully irrigated treatment (FI) was designated to receive near full soil water replacement for the depletion in the upper 1.5 m of the soil profile while allowing about 25 to 30 mm for rainfall storage. The irrigation control was based on biweekly to weekly soil water measurements using a Campbell neutron probe (model 503DR, Campbell Pacific Nuclear Corp., Martinez, CA). The neutron probe was calibrated to the Pullman soil (Evett and Steiner, 1995), and 16-s readings were taken from 0.2-m to 2.4-m depth in 0.2 m increments. One neutron tube was installed in each replication of the furrow diked, fully irrigated (FD, FI) plots. The limited irrigation treatment (LI) was irrigated at the same time as the FI plots, but the system speed was doubled to apply one-half the amount that the FI treatment received.

Yields were taken by hand harvesting two, 6.56-m long row sections from differing planter passes for a 10 m^2 sample area. The plants and ears were counted. The ears were removed from the shucks and oven dried at 70EC until no mass change was observed. Then, the grain was shelled from the cob and weighed. Kernel mass was determined from 250 kernel sub-samples from each row sample. Row samples were averaged to determine each plot's yield parameters. Grain yields are reported at standard 15.5% water content (wet basis), and kernel mass is expressed on a dry basis. Data were analyzed using standard analyses of variance and mean difference methods using Sigma Stat (v2.03, SPSS Inc., Chicago, IL).

RESULTS AND DISCUSSION

The different environments of each season are characteristic of the climatic variability in the Southern High Plains (see Howell et al., 2000). Figure 1 illustrates the March (DOY 60) through September (DOY 273) rainfall recorded near the plot area in comparison with the 50-yr mean Bushland rainfall and the FI irrigations applied in each season. The 1997 season was wetter than normal during April and August, but rainfall averaged 8% below normal for the April through October growing season. The 1998 season was the driest summer in Bushland's history until a large rain occurred in late October. The April through October rainfall was still 26% below normal. Rainfall in 1999 was more evenly distributed, except for August and October, but the growing season rainfall was only 7% above normal. Growing season temperatures and grass reference ET were similar in 1997 and 1999. The advective and drier summer of 1998 was especially noticeable in the lower dew point temperatures and larger grass reference ET values in May and June coupled with the lower season rainfall. These seasonal rainfall amounts and the fine textured soil would indicate the likelihood for yield increases from the furrow diking (Wiyo et al., 2000).

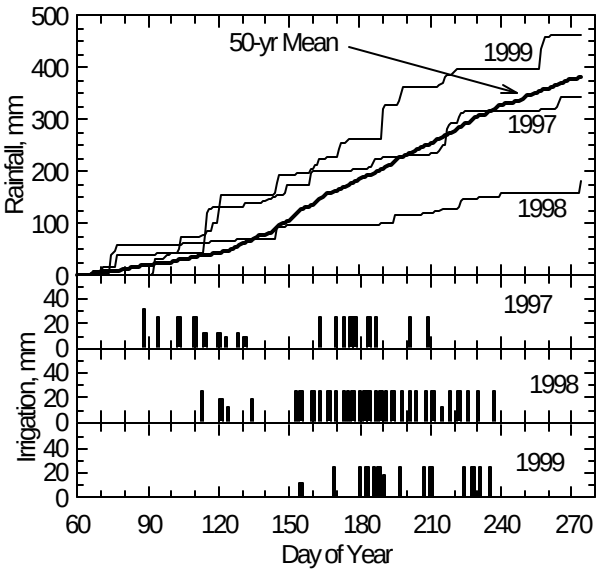

Figure 1. March (DOY 60) through September (DOY 273) rainfall during the three growing seasons and the FI applied irrigations in each season.

Soil Water

Total applied water (sum of irrigation plus rainfall) to FI was smallest in 1999 at 660 mm and largest in 1998 at 833 mm. Soil water depletion (data not shown) did not vary significantly among the treatments in 1997, but the differences between FI and LI were significant ($P<0.05$) in 1998, and the tillage treatments were slightly different ($P<0.10$) in 1999. These results are consistent with other dryland studies in semi-arid climates that indicate furrow dikes are only effective during above-normal rainfall seasons. The dense B21t horizon in the Pullman soil should likely minimize deep percolation losses reported for coarser soils. Soil water at harvest was significantly ($P<0.05$) affected by irrigation in 1997 and 1998, but not in 1999 when soil water was significantly less in the FT and BT treatments than in the FD treatment. In all years, the soil water contents declined during the growing season from deeper water profile extraction (mainly in the 0.8 m to 1.5 m depths) that could not be replaced by the 25-mm application depths that are typical for center pivot sprinklers. Irrigations were applied as often as three times per week according to ET demand and the measured soil water contents. In 1997, the profile water contents were maintained in a range generally considered "adequate." However, in both 1998 and 1999 the soil water profile water levels for FI may have induced water deficits that could have reduced grain yields. The possible soil water deficits that were observed in 1998 and 1999 may have caused the reduced mean corn yields of the FI treatments in those years. However, the FI yields of the mean FD, FI treatment had a coefficient of variation less than 0.05 Mg ha^{-1}. Tolk et al. (1998) attributed less water uptake in the Pullman soil by corn to limited extraction from deeper profile levels (below 1.5 m). McFarland et al. (1991) reported increased soil water contents with rainfed corn with diking alone or with conservation tillage with or without diking in a below-average rainfall year. The high irrigation application rate of the spray system may have led to reduced water storage capacity of FD under the FI and LI regimes due to dike siltation from the bed sides.

Grain Yield and Yield Components

The grain yield was significantly affected by the growing season, surface tillage and irrigation regimes. Grain yields (Table 1) were not significantly different between 1997 and 1999, but they were significantly less in 1998 due to the drought and a heavy infestation of smut (*Ustilago zeae*), particularly in the LI treatments. The smut infestation affected up to 75% of the ears in some of the LI plots. The smut was a regional problem that year due to the drought, high incidence of plant injury from the high wind speeds, and certain hybrid lines that had an unusual susceptibility to the disease, like Pioneer 3225 that we used that year. The low yields in the LI treatments in 1998 were responsible for the significant year X irrigation

Table 1. Grain yields, kernel mass, and kernel number for 1997, 1998, and 1999 growing seasons for corn as affected by treatments.

Treatment		Grain Yield†	Kernel Mass†	Kernel Number
1997		Mg ha^{-1}	mg kernel^{-1}	kernels m^{-2}
	Full Irrigation			
	FD	14.49 a‡	273 a	4576 a
	FT	13.58 a	260 ab	4408 a
	BT	13.74 a	260 ab	4546 a
	Limited Irrigation			
	FD	8.86 b	242 c	3149 b
	FT	8.62 b	248 bc	2991 b
	BT	7.88 b	245 c	2760 b
	$LSD_{0.05}$	1.81	13	574
1998				
	Full Irrigation			
	FD	14.19 a	269 a	4536 a
	FT	11.75 ab	259 ab	3891 ab
	BT	10.01 b	254 b	3382 b
	Limited Irrigation			
	FD	2.30 c	269 a	736 c
	FT	1.50 c	259 ab	496 c
	BT	1.47 c	254 b	497 c
	$LSD_{0.05}$	2.59	14	746
1999				
	Full Irrigation			
	FD	13.38 a	274	4207 a
	FT	11.18 b	261	3689 b
	BT	10.87 b	262	3570 b
	Limited Irrigation			
	FD	10.40 b	264	3393 b
	FT	8.44 c	269	2696 c
	BT	8.63 c	258	2877 c
	$LSD_{0.05}$	1.37	ns	344

† Grain yield expressed at 15.5% water content wet basis. Kernel mass is expressed on a dry basis.
‡ Means within a year followed by different letters are statistically different ($P<0.05$).

regime interaction (see Howell et al., 2000), while all other interactions were not significant. FD significantly increased the mean corn yield by 1.40 Mg ha^{-1}, while mean yields were not different between the FT and BT treatments. The deficit irrigation treatment significantly reduced the mean yield in all years, but the greatest mean separation occurred in 1998.

The treatment mean grain yield, kernel mass, and kernels per unit area are given in Table 1. The LI treatment reduced grain yields of all tillage treatments in 1997 and 1998, but the FD treatment improved the LI yield in 1999. In 1997, the tillage treatments did not affect grain yield, but the LI treatments reduced kernel numbers due to a smaller ear size. In 1998 under the FI regimes, FD significantly increased grain yield compared with BT mainly by increasing kernel mass and ear size. In 1999, FD significantly increased grain yield in both the FI and LI treatments mainly through increased ear size since ear density was not different among the treatments. In 1999, the FD, FI grain yield was less than the FD, FI grain yields in 1997 and 1998 by almost 1.0 Mg ha^{-1}, and this may have been the result of the lower profile soil water in 1999 following the summer drought in 1998. At comparable N fertility, McFarland et al. (1991) did not report a yield benefit for FD of corn or an effect on leaf and grain N levels under rainfed conditions. They did indicate a tendency for FD to reduce yields under higher rainfall levels. Our results did not support that tendency under FD and FI regimes or even under LI regimes on the Pullman soil.

Furrow diking treatments did not consistently increase corn yields with the LI regime, as anticipated, but FD did appear more effective in the normal to wetter season in 1999 (Table 1). Unfortunately, the smut damage to the LI treatments in the drought season of 1998 obscured any FD effects on grain yields when we would have expected the greatest benefit in line with McFarland et al. (1991). Schneider and Howell (1998) using FD reported no significant yield differences between overhead spray (comparable to this study) and LEPA in the sock mode. Their 100% and 50% irrigation mean grain yields were similar to the FI and LI treatment grain yields in 1997 and 1999 in this study. Tolk et al. (1998) reported smaller yields in 1996 for corn that was fully irrigated to meet ET use in rain sheltered lysimeters than we obtained for the FI treatment. They used a lower plant density (6 plants m^{-2}), which may have accounted partially for the lower yields. Their 50% irrigation treatment had comparable yields to our LI treatments in 1997 and 1999.

CONCLUSIONS

Furrow diking of fully and limited irrigated corn significantly increased grain yields across three growing seasons compared with other surface tillage systems. Conservation tillage with higher plant residues may be as effective, though, with sprinkler irrigation in this semi-arid environment. The high irrigation application rates of spray systems may lead to reduced water storage capacity of furrow dikes under these conditions due to dike erosion. In more

normal growing seasons, limited irrigation of corn (a 50% irrigation reduction) produced grain yields that were only reduced 39% (1997) and 22% (1999) in comparison with a more fully irrigated treatment. The drought season of 1998 clearly shows the risks associated with not fully irrigating corn in this semi-arid environment when an 85% reduction in yield occurred with deficit irrigation (a 50% irrigation reduction).

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SPRINKLER IRRIGATED WHEAT EFFICIENTLY USES FRACTIONS OF SPRING PET . . .

By Arland Schneider

A sprinkler irrigation study, conducted during the 1997-98 and 1998-99 wheat seasons, illustrated that winter wheat efficiently utilizes water applied as fractions of spring evapotranspiration (ET) calculated by the North Plains

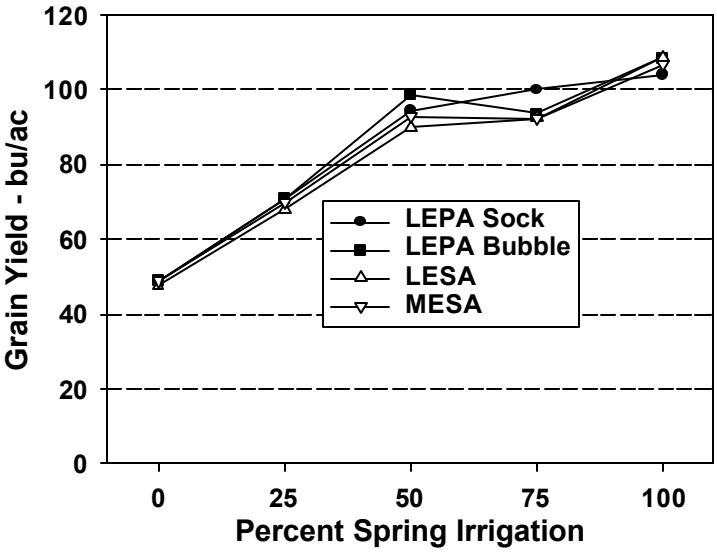

Figure 2. Variability of winter wheat yields with percent of spring irrigation.

PET Network. Two-year average wheat yields with 100% or full irrigation applied with the LEPA (low energy precision application), LESA (low elevation spray application) and MESA (mid-elevation spray application) sprinkler methods exceeded 100 bu/ac (Fig.2). With 50% of the water applied for full irrigation, wheat yields still averaged between 90 and 100 bu/ac for the three sprinkler methods. Irrigation water use efficiency, calculated as bushels per acre inch of spring irrigation, was largest with 25 and 50% irrigation.

Irrigating winter wheat with fractions of PET (as used here, grass reference ET or ETo) is especially well suited to a limited irrigation water supply from low producing wells. Planting and emergence irrigation can be staggered over an interval of a month or more, when winter water use is low. During the spring when water use exceeds the capacity of wells, irrigation at only a fraction of the ET still results in highly efficient irrigation water use.

The Ogallala variety wheat was planted in early October, uniformly irrigated as necessary for crop establishment and rooting development, and then irrigated with fractions of ET during the spring. The full or 100% irrigation treatment received sufficient 1-in. irrigations to meet full ET as provided by the North Plains PET Network. Deficit irrigation treatments received the percentages of the 100% irrigation illustrated in Fig. 2. The wheat was planted on fallowed land with a seeding rate of 60 lb/ac in 10-in. spaced rows running perpendicular to the movement of a lateral move irrigation system. Additional nitrogen was applied to bring the soil available nitrogen to 200 lb/ac, and 100 lb/ac phosphorus was applied during the previous summer. All sprinkler devices were spaced 5 ft apart and at the appropriate height on a three span lateral move irrigation system.

Grain yields and water use efficiency did not vary significantly among the LEPA and spray sprinkler methods, except for irrigation water use efficiency in 1998. That year the 75 and 100% spray-irrigated wheat lodged due to weight of the sprayed water on the tall wheat. As a result, the combine-harvested LEPA-irrigated yields were larger than the spray-irrigated yields. Hand harvested samples showed the amount of combine harvesting yield loss, and the yields shown in Fig. 2 for the spray irrigated yields for 75 and 100% irrigation were adjusted to reflect the correct grain yield of the wheat.

Water use efficiencies were calculated for seasonal water use consisting of irrigation, rainfall, and soil water depletion and then using spring irrigation and rainfall only. Seasonal water use efficiency was largest at 3.6 bu/ac-in. with 50% irrigation, ranged from 3.1 to 3.2 bu/ac-in. for the other irrigation amounts and fell to 2.4 bu/ac-in. with no spring irrigation. Spring irrigation water use efficiency was highly efficient for 25 and 50% irrigation at 6.2 and 6.4 bu/ac-in., respectively. It dropped to 4.4 and 3.9 bu/ac-in., respectively, for 75 and 100% irrigation.

Seed mass for the four spring irrigation treatments only ranged from 29.8 to 30.4 mg/seed; thus, indicating good seed weight across the treatments. The uniform seed mass also indicated that seed number per acre was the dominant factor determining yields. Harvest index, the grain fraction of above ground dry matter, ranged from 0.27 to 0.31 with spring irrigation and was significantly smaller at 0.22 without spring irrigation. The harvest index values indicate that Ogallala is a taller wheat with high yield potential. Seed mass and harvest index did not vary among the sprinkler methods.

Newsletter . . .

The *Wetting Front* newsletter is designed to foster technology transfer from our research to industry and to agricultural producers in the Southern High Plains and to improve communications with our stakeholders and partners. For actions or corrections to our mailing list, contact Mrs. Carole Perryman by fax [(806) 356-5750], e-mail (cperryma@ag.gov), phone [(806) 356-5749], or mail [USDA-ARS, P.O. Drawer 10, Bushland, TX 79012]. The *Wetting Front* can also be found on the WWW at http://www.cprl.ars.usda.gov/wmru/wfront.htm. Any suggestions or comments are welcome.

Internet News . . .

New at http://www.cprl.ars.usda.gov/programs/ are PDF files of:

- A Primer on TDR Probe Construction (updated) by Steve Evett and Brice Ruthardt
- Build and Use a Shear for Cutting TDR Probe Rods by **Steve Evett**

- Construction of a Depth Control Stand for Use with the Neutron Probe by **Steve Evett**. 7 pp. USDA-ARS-CPRL, Bushland, TX. 2000.
- Nuclear Gauge Module I, Design, Theory, and Operation by **Steve Evett**. 23 pp. In Nuclear Gauge Train-the-Trainer Course, USDA-Radiation Safety Staff, Beltsville, MD. 2000.
- **Schwartz, R.C., P.W. Unger**, and **S.R. Evett**. Land Use Effects on Soil Hydraulic Properties. In Proceedings of the 15th Conference of the International Soil Tillage Research Organization, July 2-7, 2000, Ft. Worth, TX.
- **Evett, S.R**. Energy and Water Balances at Soil-Plant-Atmosphere Interfaces. Chapter 5, Section A, CRC Handbook of Soil Science, CRC Press. 1999. (updated with errata as of 16 May 2000).
- Soil Moisture by Appearance and Feel: PDF files with graphics (USDA-NRCS).

Interesting and new web sites to visit:

- Plains Cotton Growers, Inc. http://www.plainscotton.org/
- Texas Wheat Producers Board & Association http://www.texaswheat.org/
- Texas Grain Sorghum Board http://www.sorghumgrowers.com/texas/tgsb.htm
- ARS Office of Scientific Quality Review http://www.OSQR.ars.usda.gov/
- Water Quality and Management National Program #201 Annual Report http://www.nps.ars.usda.gov/programs/npar.cfm?npnumber=201
- Web based unit conversion site http://www.webcom.com/legacysy/convert2/
- *"Free"* agricultural photography http://www.farmphoto.com/

Awards and Recognitions . . .

Steve Evett received a President's Citation from the Texas Council of Chapters, Soil and Water Conservation Society, June 23, 2000, "In Recognition of Your Leadership and Coordination of the Annual Meeting in Tyler."

Steve Evett, **Terry Howell**, **Karen Copeland**, and **Don Dusek** received Recognition for ARS Y2K Team effort, June 30, 2000, from **Dr. Floyd P. Horn**, ARS Administrator.

Terry Howell received the 2000 Hancor Soil and Water Engineering Award from the American Society of Agricultural Engineers at their annual international meeting at Milwaukee, WI, on July 11.

The **NP-PET Network Team** was recognized for being outstanding employees at the 4th Annual State and Public employee recognition at Amarillo College on August 24, 2000, by the Texas House of Representatives from the **Honorable Texas Representative David Swinford** of Dumas, TX.

Brice Ruthardt, **Jim Cresap**, **Keith Brock**, and **Carole Perryman** received a "superior" annual performance rating and award for service to the Research Unit and the laboratory.

Terry Howell was selected as the Outstanding Senior Research Scientist for the Southern Plains Area. The award will be presented at the annual ARS Awards Ceremony at Beltsville, MD, in February.

Grant News . . .

Terry Howell received $10,250 from the Texas Agricultural Experiment Station for the state fiscal year 2001 for the PROFIT (Productive Rotations on Farms in Texas) project for proposal #12-9901 "High Plains Cropping Systems" for cooperative research with **Dr. Brent Bean**.

The U.S. Civilian Research and Development Foundation granted **Steve Evett** and **Dr. Nazirbay Ibragimov**, his co-principal investigator in Uzbekistan, $68,000 to support their proposal titled "Improving Water Use Efficiency/Reducing Salinization in Irrigated Wheat and Sugar Beet Production." Dr. Ibragimov is Head of the Fertilizer Department of the Uzbekistan National Cotton Growing Research Institute (UNCGRI). Other investigators are **Dr. Bakhtiyor Kamilov**, Head of the Irrigation Department, UNCGRI, and **Maksudkhon Sarimsakov**, also of the UNCGRI.

The International Atomic Energy Agency granted co-investigators **Steve Evett**, **Judy Tolk**, **Terry Howell**, and **Arland Schneider** $10,000 to support their research project titled "Accuracy and Precision of Neutron Scattering, TDR, and Capacitance Methods of Soil Water Measurement." The funds will be combined with funds contributed by the High Plains Underground Water Conservation District #1, Lubbock, TX ($5,000); the North Plains Groundwater Conservation District #2, Dumas, TX ($4,000), and the Panhandle Ground Water Conservation District #3, White Deer, TX ($2,000).

Upcoming Events, Meetings, and Presentations . . .

EVENT:

Sept. 7, 2000 — Seminar about the Texas Panhandle Water Plan, TAES Agricultural Research & Extension Center at Amarillo, 3:00-5:00 PM. Speakers: **John Sweeten** and **Nolan Clark**.

Oct. 17, 2000 – Dedication of the Graham-Hoeme chisel Plow as an ASAE Historical Landmark at the USDA-ARS Conservation & Production Research Laboratory, Bushland, TX. **Contact:** Dr. Nolan Clark, (806) 356-5734 or rnclark@ag.gov.

FIELD DAYS:

September 13, 2000 – Grain sorghum PROFIT field tour starts at 9:00 AM at Bushland. **Contact:** Brent Bean (806) 359-5401 or b-bean@tamu.edu.

UPCOMING MEETINGS:

Sept. 11-12, 2000 — "USDA-ARS Agricultural Systems Models for Information and Technology Transfer", Beltsville, MD.

Oct. 16-20, 2000 — "International Symposium on Nuclear Techniques in Integrated Plant Nutrient, Water and Soil Management," Vienna, Austria.

Oct. 25-27, 2000 — Texas Section ASAE Meeting, Waco, TX. http://asae.org/sections/tx/texas.html

Nov. 5-9, 2000 — ASA/SSSA/CSSA Annual Meeting, Minneapolis, MN. http://www.asa-cssa-sssa.org/olr99/

Nov. 12-14, 2000 — 21st Annual International Irrigation Show, Phoenix, AZ. http://www.irrigation.org/ia/expo/2000Expo/index.html

Nov. 14-16, 2000 — "4th Decennial National Irrigation Symposium," ASAE & IA, Phoenix, AZ. **Contact:** Dr. Derrel Martin, Univ. of Nebraska, Biol. Systems Engr. Dept., L.W. Chase Hall, Lincoln, NE 68583-0726, (402) 472-1586, (402) 472-6338 (fax), dmartin@unlinfo.unl.edu. http://asae.org/meetings/irrigation00/index.html

Nov. 29-Dec. 1, 2000 — ARS Water Management Workshop, Irving, TX. Planning CRIS projects for ARS National Program #201 on Water Quality and Management. http://www.nps.ars.usda.gov/programs/nrsas/201/ACTionplan/

UPCOMING PRESENTATIONS:

October 16-20, 2000 — "International Symposium on Nuclear Techniques in Integrated Plant Nutrient, Water and Soil Management", Vienna, Austria. **Steve Evett** will present the keynote address for session 3, Soil Water Management and Conservation titled "Exploits and Endeavors in Soil Water Management and Conservation Using Nuclear Techniques."

November 5-9, 2000 — ASA/SSSA/CSSA Annual International Meeting, Minneapolis, MN.

- **Steve Evett** will present "Thermal Conductivity from TDR and Temperature Measurements in Three Southern Plains Soils" (co-author: **Judy Tolk**)
- **Rick Todd** will present "The Bowen ratio-energy balance method evaluated in the semiarid advective environment of the south High Plains" (co-authors: **Steve Evett**, and **Terry Howell**)
- **Laj Ahuja** will present "Whole System Integration and Modeling—Essential to Agricultural Science and Technology in the 21st Century" (co-authors: **Terry Howell**, **C.R. (Dick) Amerman**, and **Mark Weltz**)
- **Judy Tolk** will present "Water Use-Yield Relationships of Corn and Sorghum Grown in Three High Plains Soils" (coauthor: **Terry Howell**)

November 14-16, 2000 — "4th Decennial National Irrigation Symposium", Phoenix, AZ:

- **Steve Evett** will present "Alfalfa Reference ET Measurement and Prediction" (co-authors: **Terry Howell**, **Rick Todd**, **Arland Schneider**, and **Judy Tolk**), and "Automatic Drip Irrigation of Corn and Soybean" (co-authors: **Terry Howell**, **Arland Schneider**, **Dan Upchurch**, and **Don Wanjura**)
- **Terry Howell** will present the keynote address, "Irrigation's Role in Enhancing Water Use Efficiency" and "Irrigated Fescue Grass ET Compared with Calculated Reference Grass ET" (co-authors: **Steve Evett**, **Arland Schneider**, **Don Dusek**, and **Karen Copeland**), and **Terry Howell** is a co-author of "Issues, Requirements and Challenges in Selecting and Specifying a Standardized ET Equation" authored by **Richard G. Allen** et al., "ASCE Standardized Reference Evapotranspiration Equation(s)" written by **Ivan A. Walter** et al., "The Role of Automated Weather Networks in Providing Evapotranspiration Estimates" written by **Ron Elliott** et al., and "Comparison Between Evapotranspiration References and Methods" written by **Jim Wright** et al.
- **Arland Schneider** will present "LEPA Irrigation Developments" (co-authors: **Gerald Buchleiter** and **Dennis Kincaid**)
- **Judy Tolk** will present "Measured and Predicted Evapotranspiration of Grain Sorghum Grown with Full and Limited Irrigation in Three High Plains Soils" (co-author: **Terry Howell**).

Technology Transfer News . . .

CUSTOMER/CLIENTELE NEEDS:

On March 6-10, 2000, **Brice Ruthardt**, **Karen Copeland**, **Don Dusek**, and **Terry Howell** attended the "Automated Weather Network Workshop" at the University of Nebraska.

On March 28, 2000, **Arland Schneider** and **Terry Howell** attended the Netafim Cotton Drip Irrigation Meeting at Lubbock, TX.

Steve Evett, **Arland Schneider**, and **Judy Tolk** attended the Golden Spread Chapter, Soil and Water Conservation Society meeting at the Wildcat Bluff Nature Center, Amarillo, TX on March 28, 2000. **Judy Tolk** was in charge of the program and led a walking tour of the area's ecology.

On May 6-7, 2000, **Terry Howell** attended the 2000 ASA/SSSA/CSSA program development meeting in Milwaukee, WI.

On June 1, 2000, the **Water Management Unit** participated in the "Wheat Field Day" at Bushland. **Arland Schneider** presented a talk on "Advances in Irrigation Efficiency."

On June 6, 2000, **Steve Evett** conducted an eight-hour radiation safety and hazardous materials transport training for the use of nuclear gauges in soil moisture and density measurements. Participants included employees of USDA-ARS, Bushland, TX and Woodward, OK; Texas Agricultural Experiment Station in Amarillo and Lubbock; and West Texas A&M University, Canyon.

On June 16, 2000, **Steve Evett** presented "Irrigation Automation and Crop Water Use (ET)", **Arland Schneider** presented "Sprinkler Irrigation Systems and Application Devices", and **Judy Tolk** presented "Soil and Crop Type and Irrigation Efficiency" during a tour by the Dryland Agriculture Institute Workshop, West Texas A&M University.

Steve Evett, **Judy Tolk**, **Robert Schwartz**, and **Andy Cole** attended the 34th Annual Meeting of the Texas Council of Chapters, Soil and Water Conservation Society in Tyler, Texas, June 20-23. The meeting featured three technical sessions: A technical tour to the Victor Hill Breed Farm that included five speakers on poultry litter, nutrient, and mortality management (3 continuing education units); a Nutrient/Animal Manure Management Workshop with five speakers (4 CEUs); and an all-day technical program, "Nutrient and Animal Manure Management Challenges in the New Millennium" with nine speakers (8 CEUs). **Steve Evett** was program chair for the meeting.

On June 20-23, **Terry Howell** participated in the ASCE-EWRI "Watershed Management 2000 Conference" at Fort Collins, CO and in the Evapotranspiration in Irrigation and Hydrology Committee and the Irrigation and Drainage Council Meetings.

On June 30, **Terry Howell** discussed furrow diking with the ISTRO-2000 tour at Bushland, TX.

On July 2-4, 2000, **Terry Howell** participated in the ISTRO-2000 Conference in Fort Worth, TX.

Terry Howell participated in the 2000 ASAE Annual International Meeting at Milwaukee, WI on July 9-12, 2000.

Terry Howell met with the ASCE Environmental and Water Resources Institute Awards Committee on July 22, 2000, at Kansas City, MO.

On July 12, 2000, **Judy Tolk** presented "Soil and Crop Type and Irrigation Efficiency" and **Arland Schneider** presented "Irrigation Automation and Crop Water Use" and "Sprinkler Irrigation Systems and Application Devices" for a tour of visitors from West Africa organized by USDA-FAS.

On August 7, 2000, **Terry Howell** and **Louis Baumhardt** met with **Dr. Bobby Eddleman** at Amarillo regarding economic analyses of the PROFIT study data.

On August 10, 2000, **Dr. Maria Balota**, Fulbright Visiting Scholar with TAES, presented "Physiological Traits to Efficiently Discriminate for Drought Resistance in Winter Wheat" at the Texas Small Grains Workers Annual Meeting at the Texas A&M Center in Amarillo. The report detailed work done in cooperation with second author **Steve Evett** using hand held and data logged infrared thermometers to measure canopy temperature depression of three wheat cultivars with differing drought resistance. **Steve Evett**, **Judy Tolk**, **Terry Howell**, and **Karen Copeland** attended the meeting.

On August 30, 2000, **Terry Howell** met with Daniel Stomp with Valmont Irrigation at Bushland to discuss lateral-move sprinkler irrigation.

MEDIA CONTACTS:

Arland Schneider was interviewed by **Richard Porter** of the *Plainview Daily Herald* concerning runoff from LEPA and spray irrigation on March 16, 2000.

On March 17, **Steve Evett** was interviewed by **Mr. Bruce Gaarder** of Agrinet Radio, Oklahoma City, about our work in Uzbekistan. Discussion centered on the need for scientific irrigation scheduling to prevent salinization, and the crops being targeted for increased production there (wheat and sugar beet). Also discussed were the irrigation systems used (mostly furrow from concrete lined canals and laterals, but some center pivots).

Arland Schneider was interviewed for the CREET Beat by **Larry DeSha** of KGNC Radio on March 29, 2000

Arland Schneider and **Terry Howell** were interviewed about sprinkler irrigation by French journalist, **Emmanuel Monnier**, on April 14, 2000. The interview resulted in USDA information being presented in the French journal *Science & Vie*.

Arland Schneider was interviewed regarding cotton irrigation with **Bruce Gaarder** of the Oklahoma Agrinet Radio, Oklahoma City, on June 1, 2000.

Judy Tolk was interviewed for the CREET Beat, KGNC radio, by **Larry DeSha**, and discussed soil type effects on yield on June 30, 2000.

VISITORS:

From March 7 through 10, 2000, **David Bryla**, Plant Physiologist with USDA-ARS Water Management Research Unit, Fresno, CA, visited to train on the TACQ software for control of a time domain reflectometry (TDR) system for soil water content measurement, and how to construct coaxial multiplexers and TDR probes.

On March 9 and 10, **Sheri Anderson**, Technician with USDA-ARS, Lubbock, TX, (working with **Dr. Bobbie McMichael**), visited to train about TDR probe construction and the TACQ software.

Dr. Z.J. Sun, ESI Environmental Sensors, Inc., Victoria, Canada, visited **Steve Evett** on June 1-3, 2000, for discussions on the use of TDR for soil water content measurement.

SEMINARS/PRODUCER/CLIENTELE MEETINGS/ PRESENTATIONS:

On March 22, 2000, **Terry Howell** attended the USDA-NRCS Water Management Conference at Boise City, OK, and presented "Irrigation Scheduling."

Ivan Walter presented "ASCE's Standardized Reference Evapotranspiration Equation" co-authored with **Rick Allen**, **Ron Elliott**, **Marvin Jensen**, **Daniel Itenfisu**, **Bent**

Mecham, **Terry Howell**, **Rick Snyder**, **Paul Brown**, **Simon Echings**, **Tom Spofford, Mary Hattendorf**, **Dick Cuenca**, **Jim Wright**, and **Derrel Martin** at the ASCE Environmental and Water Resources Institute Watershed Management 2000 Conference in Fort Collins, CO, on June 20-23, 2000.

On July 2-4, 2000, **Terry Howell** presented a poster co-authored with **Arland Schneider** and **Don Dusek** at the ISTRO-2000 Conference on "Effects of Furrow Diking on Maize Response to Limited and Full Irrigation" in Fort Worth, TX. **Robert Schwartz**, **Paul Unger**, and **Steve Evett** presented the poster "Land Use Effects on Soil Hydraulic Properties."

On July 9-12, 2000, **Terry Howell** presented a paper co-authored with **Arland Schneider** and **Don Dusek** at the 2000 ASAE Annual International Meeting on "Effects of Furrow Diking on Corn Response to Limited and Full Irrigation" in Milwaukee, WI.

On August 16, 2000, **Steve Evett** presented "Infrared thermometry for Remote Sensing of Plant Stress" to the Precision Agriculture class of **Dr. Clay Robinson**, West Texas A&M University, and gave the class a field tour of research projects using infrared thermometers.

On August 18, 2000, **Steve Evett** and **Arland Schneider** presented "Crop Water Use and Irrigation Automation", and "Sprinkler Irrigation Systems and Application Devices" for a West Texas A&M University Dryland Agriculture Institute Workshop tour from the Peoples Republic of China.

Steve Evett presented a seminar on "Time Domain Reflectometry (TDR) for Soil Water Content Measurement" at the USDA-ARS Plant Stress and Water Conservation Laboratory at Lubbock, TX, in cooperation with TAES and Texas Tech University on August 30, 2000

POPULAR MAGAZINE ARTICLES:

The July 2000 issue of *Cotton Farming* included an article by **Shannon Holman** titled "Automated Irrigation May Help High Plains" that discussed the research on automatic drip irrigation of cotton that is being conducted at Lubbock, TX, by **Dr. Robert Lascano**, TAES, and which uses the automatic soil water content measurement system developed by **Steve Evett**.

CRADA/INTER-AGENCY COLLABORATION:

A CRADA is still being finalized with a large swine producer in the Texas High Plains on "Sustainable Irrigation for Swine Production in the Southern High Plains" to identify water efficient cropping systems to utilize swine waste effluent in a semi-arid environment adapted for center pivot sprinkler irrigation to avoid impacting surface and ground water quality.

OTHER TECHNOLOGY TRANSFER ACTIVITIES:

Judy Tolk discussed plants with a group of 16 Cub Scouts from Puckett Elementary in Amarillo on April 10, 2000.

Arland Schneider spoke about "Careers in Agriculture" at the Annual Career Day at Southlawn Elementary School on May 4, 2000.

Steve Evett provided advice and counsel on the use of the neutron probe, time domain reflectometry, and capacitance methods of soil water content measurement to **Dr. Phil Goyne**, Hermitage Research Station, Warwick, Queensland, Australia; **Russell Millard**, Wellington, New South Wales, Australia; Richard Morel, RMC, Kingston, Ontario, Canada; **Gregg Dill**, PE, Alberta Agriculture, Lethbridge, Alberta, Canada; **Dr. L.K. Heng**, International Atomic Energy Agency, Vienna, Austria; **Ken Kephart**, Superintendent, MSU Southern Ag. Res. Center, Huntley, MT; **Ingvard Find**, McCain Foods Limited; **Dr. Michael Young**, Desert Research Institute, Las Vegas, NV; Jason Ritter, Pacific Northwest Laboratories; **Dr. Jian Zhou**, Iowa State University, Ames, IA; **Bruce Metelerkamp**, SOWACS, New Zealand; Texas Cattle Feeders Association, Amarillo, TX; **Dr. Md. Abdul Mojid**, Saga University, Japan; **Arturo Romanillos**, TAES, Amarillo, TX; **Dr. Bobbie McMichael**, USDA-ARS, Lubbock, TX; **Dr. John Matocha**, Soils & Plant Nutrition/Professor, TAES, Corpus Christi, TX; and **Dr. Scott VanPelt**, USDA-ARS, Big Spring, TX.

Steve Evett provided advice and counsel on the use of the Energy and Water Balance Model ENWATBAL to **Dr. John Zhang**, USDA-ARS, El Reno, OK; **Dr. Masoud Edraki**, CSIRO Land & Water, Griffith, Australia; and **Dr. Giovanni Muñoz**, Mediterranean Agronomic Institute, Bari, Italy.

Judy Tolk provided sap flow articles to a student in Sweden; information concerning the measurement of transpiration to a civil engineering student at the Univ. of Florida; publications on the research at the SPER facility to an Ethiopian PhD student at the Asian Institute of Technology in Thailand; continued assistance on leaf water potential measurements with **Dr. Maria Balota**, Fulbright Visiting Scholar with TAES.

Recent Publications (since February 2000) . . .

Howell, T.A., A.D. Schneider, and D.A. Dusek. 2000. Effects of furrow diking on maize response to limited and full sprinkler irrigation. Proc. 15th Conference of the International Soil Tillage Research Organization. 15 p.

Howell, T.A., A.D. Schneider, and D.A. Dusek. 2000. Effects of furrow diking on corn response to limited and full sprinkler irrigation. ASAE Paper No. 00-2022, 18 p.

Schwartz, R.C., P.W. Unger, and S.R. Evett. 2000. Land use effects on soil hydraulic properties. Proc. 15th Conference of the International Soil Tillage Research Organization. 2000. 10 p.

Todd, R.W., S.R. Evett, and T.A. Howell. 2000. The Bowen ratio-energy balance method for estimating latent heat flux of irrigated alfalfa evaluated in a semi-arid, advective environment. Agriculture and Forest Meteorology 103:335-348.

Vick, B.D., R.N. Clark, and S.R. Evett. 2000. Wind-powered drip irrigation systems for fruit trees. ASAE Paper No. 00-4030.

Walter, I.A., R.G. Allen, R. Elliott, M.E. Jensen, D. Itenfisu, B. Mecham, T.A. Howell, R. Snyder, P. Brown, S. Echings, T. Spofford, M. Hattendorf, R.H. Cuenca, J.L. Wright, D. Martin. 2000. ASCE's Standardized Reference Evapotranspiration Equation. *In* Marshall Flug and Donald Frevert (eds.) *Science and Engineering Technology for the New Millennium*, proceedings of the Watershed Management 2000 Conference, Environmental and Water Resources Institute (ASCE), Reston, VA.

Personnel News . . .

Arland Schneider participated in the USDA-ARS Congressional Briefing Conference in Washington, D.C., on Mar. 20-23, 2000.

Carole Perryman and **Don McRoberts** were promoted.

Jack Musick died on March 24, 2000. Our deepest sympathies are extended to Clara, his wife, and his family. Jack's immense knowledge of irrigation and the Great Plains will be greatly missed within our unit and our laboratory.

Don Dusek retired on April 7, 2000, with 37 years of service to USDA-ARS. He was retained in a collaborator status to complete some data processing. He was immediately hired by the Texas Agricultural Experiment Station as a Research Associate in Amarillo to continue his programming and operation of the automated weather station network for the NP ET network. He didn't even move offices!

Steve Evett began his term as President of the Texas Council of Chapters of the Soil and Water Conservation Society.

Judy Tolk will begin her term as President of the Golden Spread Chapter of the Soil and Water Conservation Society in September.

Carole Perryman served in a temporary duty position in the Southern Plains Area Office in College Station, TX from April 24–May 5. She attended CFC training on August 23, 2000. We really appreciate Carole's willingness to tackle these extra assignments while still keeping things together on the Water Management "home front."

Carole Perryman will be taking basic and advanced training at Amarillo College in September and October in Microsoft Word and Excel.

Thanks are extended to our 2000 summer students employees. **Sara Ledbetter** and **Kyle Schniederjan** returned for their fourth summer. They were joined by first-time summer employees **Paul Driscoll**, attending the Pharmacy School at Texas Tech University in Amarillo, and **Lance Miller**, a sophomore at Texas A&M University. **Kyle** married **Kelli Click** this summer, and we offer them our congratulations and best wishes.

Water Management Research Unit

http://www.cprl.ars.usda.gov

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